A Statistical Investigation of Persistence in the Israeli Artificial Rainfall Stimulation Experiment¹

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ABSTRACT

A number of tests of the data of the Israeli rainfall stimulation experiment have not shown any evidence of persistence of effects of cloud seeding, either from day to day, or within each season, or from season to season.

1. The problem of persistent seeding effects

The possibility that randomized artificial rainfall experiments may be vitiated by the persistence of seeding effects from one seeding period to another has been suggested by Bowen (1965). The National Academy of Sciences report on weather and climate modification (1966, Vol. II, p. 126) mentions “. . . a recently raised question as to whether AgI nuclei can somehow persist in a target region and produce delayed seeding effects weeks and months after release. This so-called ‘carry-over effect,’ first suspected by Grant (1963) . . . seems quite improbable on physical grounds, although weak evidence for the same effect has been reported for some of the Australian trials. If real, it will have disastrous implications for detection of seeding effects in typical randomized trials. It is an urgent problem demanding clarification.”

A simple statistical model for persistence has been described by Bowen (1966) who has discussed its effects on randomized trials. Bowen (1965, private communication) has also suggested that persistence might “. . . have a devastating effect on a conventional cross-over experiment which went on from year to year with no breaks. The effect would be much less in an experiment such as (that in Israel) which is virtually a half year on and a half year off. However, it would still show as a gradual decrease in the apparent result as (the) seeding season progressed.”

2. Analyses of the Israeli experiments' data

The present paper considers statistical evidence regarding persistence in the data of the Israeli artificial rainfall stimulation experiment. This is a winter season experiment with a randomized cross-over design using four areas aligned as follows: North, Buffer, Center and South. Seeding is assigned randomly on each day either

to the North or to the Center area. The Buffer and South areas serve only as controls. [For further details see Gabriel (1965, 1966)].

Different methods of analysis may be appropriate for checking short term persistence, of the order of a few days, than for investigating persistence of longer durations. Grant's observations apparently relate to weeks or even months and from the evidence of the Australian experiments, Smith (1966) stipulates that “. . . the half period of this process was of the order of many months.” We start by investigating evidence for long term persistence (Section 3), then turn to within-season persistence (Section 4) and finally consider data relating to day-to-day persistence (Section 5).

A number of methods of analysis are used in the different sections, and most of them can undoubtedly be adapted to the data of other rainfall stimulation experiments. Whether control regions exist or do not exist, and whether an experiment has only one seeding region or is of a cross-over type, some of these analyses can be used. Indeed, we would hope that this paper might stimulate other experimenters to check their data for persistence.

3. Evidence regarding season-to-season persistence

As illustrated in Table 1, the apparent effect of seeding was strongest in the first short season of 1961. As later results showed apparently smaller effects it was suspected that a negative trend might exist, such as would be accounted for by persistence. However, the results of the last three seasons show that there is no

TABLE 1. Ratio of rainfall with seeding to rainfall without seeding for each season [average S/NS ratio method (Gabriel, 1966)].

1961*	1961-62	1962-63	1963-64	1964-65	1965-66
1.650	1.170	1.099	1.212	1.138	1.473

* Two months only.

¹ See also pp. 437-438 this issue.

TABLE 2. Ratios of rainfall in experimental to control areas. All days, seeded and unseeded, by years.

Year	North Buffer	Center South	North+Center Buffer+South
1961	1.42	1.14	1.30
1961-62	1.02	1.96	1.27
1962-63	1.11	2.06	1.36
1963-64	1.16	1.13	1.14
1964-65	0.96	1.45	1.16
1965-66	1.17	1.17	1.17

such trend and indeed it is *a priori* unlikely that persistence could carry over the dry summer between one seeding season and the next.

Comparison of rainfall in experimental and control areas might throw additional light on the possibility of persistence. Table 2 shows ratios of total annual precipitation in each experimental area and the adjacent control area. All days are included, whether seeded in that experimental area or not, since persistence might also produce seeding effects on days on which seeding is not actually carried out. If season-to-season persistence had existed, the experimental/control ratios should have shown an upward trend with a gradually decreasing gradient. Such a trend is not evident in the figures of Table 2.

4. Evidence regarding within-season persistence

It would seem more likely that persistence might be evident within the seasons of experimentation, so that apparent effects would be highest at the beginning of the season and would decrease thereafter. Following a suggestion by Bowen (1965, private communication), we checked this by pooling the data of all the seasons in each particular month, the results being given in Table 3.

The data of this table do not show any trend of decreasing apparent seeding effect as the season goes on. In fact, the ratio is highest at the end of the season. There is no evidence of within-season persistence.

A comparison of total precipitation in experimental and control areas is given in Table 4 separately for different parts of the season. Again, there is no evidence of a gradually decreasing gradient in an upward trend, as the season progresses, such as would have been expected under persistence.

TABLE 3. Ratio of rainfall with seeding to rainfall without seeding by month. [average S/NS ratio method (Gabriel 1966)].*

Oct.-Nov.	Dec.	Jan.	Feb.	Mar.-Apr.
1.188	1.074	1.258	1.092	1.371

* The small difference between the ratios of this table and those of Table 7 of Gabriel (1966) are due to the exclusion of dry days from the latter, as well as in the 1965-66 data. The March-April figures differ more severely because the present table does not include the 1961 season which started in mid-February.

TABLE 4. Ratios of rainfall in experimental areas to control areas. All days, seeded and unseeded, by month.

Month	North Buffer	Center South	North+Center Buffer+South
Oct.-Nov.	0.85	1.46	1.06
Dec.	0.91	1.72	1.17
Jan.	1.12	1.51	1.27
Feb.	1.15	1.22	1.18
Mar.-Apr.	1.72	1.09	1.40

However, it is doubtful whether the latter table could have revealed any but very considerable persistence because there are systematic seasonal trends in those inter-area ratios. Katznelson (1958) points out that coastal rainfall generally comes earlier than rainfall in the interior regions and in the south. This accounts for the rising of the North/Buffer ratio as the buffer stations are very near the coast, and it also explains the falling trend of the Center/South ratio, most of the control stations being quite near the coast. Indeed, the main point in presenting Table 4 is to warn against the pitfalls of this method of analysis.

5. Evidence regarding day-to-day persistence

If there is persistence in the effect of AgI seeding from one day to the next, rainfall on days following AgI seeding should be heavier than on days without previous AgI seeding. This should be so on days which are seeded in the North, on days which are seeded in the Center and also on dry days (dry in the buffer). To check this, all experimental days were classified according to seeding on the day itself and on each of the two preceding days.

Table 5 presents the mean daily observations classified by seeding allocation on that day and the day before. The effect of AgI seeding is evident in the fact that the entries mostly decrease from left to right, i.e., the North-Center differences are highest under North-seeding and lowest under Center-seeding. Persistence of the effect of yesterday's seeding would similarly produce a decrease from top to bottom within each column. Of the three columns of Table 5 only one shows such an order, the other two having the highest mean at the bottom of the column rather than at the top. Clearly, this cannot be considered evidence supporting the persistence hypothesis. On the other hand, the standard errors of the

TABLE 5. Mean daily north-center difference in precipitation (mm), with standard errors, classified according to seeding on day and previous day.

Yesterday's seeding	Days' seeding		
	North	Dry day*	Center
North	3.65±1.85	0.14±0.09	-2.22±2.46
None	2.13±0.78	0.06±0.02	0.23±0.85
Center	2.12±2.22	0.23±0.12	1.50±1.34

* No precipitation in buffer area.

means are so large that they might well have obscured slight persistence if it existed.

Table 6 gives a finer breakdown of the same data, taking into account seeding on the day before yesterday

TABLE 6. Mean daily North-Center differences in precipitation (mm), with standard errors, classified by seeding on day and two previous days.

Seeding on preceding days			Days' seeding		
2nd	1st	Rank	North	Dry day*	Center
North	North	1	2.33±3.88	-0.05±0.06	-3.94±5.26
None	North	2	5.88±2.57	0.32±0.20	-0.18±3.59
Center	North	3½	-1.79±2.05	0.06±0.06	-4.13±4.72
North	None	3½	2.65±2.55	0.22±0.16	2.08±2.32
None	None	5	2.28±0.87	0.04±0.02	0.02±1.00
Center	None	6½	-0.80±0.78	0.23±0.16	0.50±1.93
North	Center	6½	-1.23±3.07	0.35±0.34	3.60±2.32
None	Center	8	-0.27±1.23	0.34±0.22	0.64±1.85
Center	Center	9	9.04±6.67	0.03±0.02	1.34±3.47

* No precipitation in buffer area.

as well. To gage the possibility of two-day persistence of seeding effect, one may see whether for any one given combination of today's and yesterday's seeding, the three means decrease as one goes down the table. Thus for north-seeded days and yesterdays, the means are +2.33, +5.88, -1.79 and no regular decrease is evident. Indeed only in 2 of the 9 triplets is the order as one would expect if effects were persistent. This can hardly be considered evidence of two-day persistence of seeding effects, even though here again large standard errors might have hidden small effects.

Another test of the existence of persistence from the two preceding days is whether the mean daily differences decrease from top to bottom in each column of Table 6. This is appropriate since the categories in the rows of the table are in decreasing order of possible persistence effects, except perhaps the order of the third and fourth rows and that of the sixth and seventh rows. Correla-

tions of the means in each column with the ranks of the rows (tying the above pairs) are (Kendall's tau) -0.06, +0.18, and +0.47 for the three columns, respectively. There is no evidence of the negative correlation one would have expected if persistence existed.

6. Conclusions

None of the tests described in this paper have shown any statistical evidence of persistence, of either long or short duration, of effects of AgI seeding of clouds. Since statistical evidence has been cited elsewhere in favor of persistence, the present findings are of importance in that they do not support this hypothesis. One hopes for further evidence by similar analyses of the data of other experiments.

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